A systematic review of motivational and attentional variables on children's fundamental movement skill development: The OPTIMAL theory.

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Abstract

An external focus of attention, enhanced expectancies and autonomy support are key independent and interactive characteristics which enhance motor learning. These OPTIMAL (Optimizing Performance Through Intrinsic Motivation and Attention for Learning) characteristics have proven supportive of adult’s motor learning yet, their effect on children’s motor learning is comparatively under-explored. Fifty-five studies were systematically reviewed to outline the impact of OPTIMAL variables on children’s motor learning, specifically foundational movement skills (FMS). Thirty-five studies examined an external focus of attention, whereas relatively few addressed enhanced expectancies (n = 12) and autonomy support (n = 8). Only 2 explored the interaction between OPTIMAL variables. Results show emerging evidence that OPTIMAL variables contribute to children’s effective motor learning. Despite this initial support, there is a paucity of research regarding the impact of OPTIMAL variables across the full FMS range (i.e. a skewness towards object manipulation skills). Moreover, children’s different developmental characteristics may moderate the beneficial effects of OPTIMAL variables. Additionally, the attentional and motivational mechanisms underpinning OPTIMAL learning in children requires future work (e.g. self-efficacy and perceived competence). Finally, there is a need for future combinatory research addressing OPTIMAL variables in children (e.g. enhanced expectancies with autonomy support). These results have theoretical and practical implications for movement specialists working with children and future OPTIMAL research.

Key words: OPTIMAL theory; external focus of attention; enhanced expectancies; autonomy support; children; foundational movement skills.

1. Introduction

The OPTIMAL (Optimizing Performance through Intrinsic Motivation and Attention for Learning) theory of motor learning (Wulf & Lewthwaite, 2016) has identified that an external focus (EF) of attention on intended movement outcomes or effects (Wulf, 2013), enhanced expectancies (EE) for successful performance (Goncalves, Cardozo, Valentini, & Chiviacowksy, 2018) and autonomy support (AS) (Lemos, Wulf, Lewthwaite, & Chivacowsky, 2017) are key attentional and motivational factors central to motor skill learning. According to the OPTIMAL theory, each factor makes independent and interactive contributions to effective goal-action coupling by priming and optimising the motor system for successful task execution (Wulf & Lewthwaite, 2016). Independently, instructions and feedback that promote an EF enhance motor performance and learning by directing attention towards the intended movement outcome or effect to promote unconscious, automatic and reflexive motor control (Wulf, 2013). Additionally, learning conditions that enhance expectancies for future successful performance and provide autonomy support through the provisions of perceived control, facilitate motor learning through motivational mediators which include self-efficacy (Bandura, 1977), perceived competence (Ryan, 1995) and positive affect (e.g., positive feelings; Stoate, Wulf, & Lewthwaite, 2012). When satisfied, these motivational factors stimulate dopamine release which contributes to neural pathway development and memory consolidation (Li et al., 2015; Sugawara, Tanaka, Okazaki, Watanabe, & Sadato, 2012). Moreover, the combinations of OPTIMAL variables have additive benefits on motor learning by further improving efficient goal-action coupling (Wulf, Lewthwaite, Cardozo & Chiviacowsky, 2018).

The application of OPTIMAL variables has been well-reported in adult populations (for review see Lewthwaite & Wulf, 2017), however it is surprising that relatively little is known about their comparative effects on children and adolescents' motor learning[1]. In adult populations, an EF has consistently been shown to improve motor learning through enhanced movement effectiveness (e.g., throwing accuracy) and efficiency (e.g., increased functional movement variability) (Lohse, Jones, Healy, & Sherwood, 2014; Marchant, 2011) when compared with an internal focus (IF) on body movements and conditions where no specific focus is instructed (see Wulf, 2013 for review). Similarly, adults' motor learning has improved when performance expectancies were enhanced: through setting out achievable performance criteria (e.g., smaller opportunity for error; Marchant, Carnegie, Wood, & Ellison, 2018; Ziv, Ochayon, & Lidor, 2019); through highlighting good performances (e.g., feedback on good trials only; Wulf, Chiviacowksy, & Lewthwaite, 2012) and suggesting that performance was better than average through (false) positive-social comparative feedback (Chiviacowsky, Cardozo, & Chalabaev, 2018).

Additionally, conditions which support a learners' need for autonomy (Deci & Ryan, 2008) have improved adults motor performance and learning through motivational mediators. Autonomy has been supported by allowing control over: the extent of practice (Post, Fairbrother, Barros, & Kulpa, 2014); the frequency of skill demonstrations (Van Maarseveen, Oudejans, & Savelsbergh, 2018); the use of assistive devices (Hartman, 2007) and by altering task variables such as performing with a dominant versus a non-dominant hand (Wulf, Lewthwaite et al., 2018). Autonomy support can also be provided through language which is 'suggestive' rather than 'controlling'. For example, providing hints ("*you may want to*") on how best to perform a task rather than direct instruction ("*you must*") (Hooyman, Wulf, & Lewthwaite, 2014). The opportunity for both task relevant (e.g., choice of when to view

[1] Adolescence is defined as populations between the age of 11-17 (Curtis, 2015). For the purpose of this review adolescent populations will be identified with the term "children".

video demonstrations) and task irrelevant choices (e.g., choice of equipment colour) have proven effective to adults motor learning, however different mechanisms have been proposed to explain the benefits (Carter & Ste-Marie, 2017; Wulf, Iwatsuki, Machin, Kellogg, & Copeland, 2018). A review by Lewthwaite and Wulf (2017) highlighted the potential effectiveness of an EF, EE and AS in adult motor learning, therefore it appears likely that OPTIMAL approaches can also optimise children's motor learning. However, to date, research with children is limited, perhaps due to more difficult access to this population, despite the importance of effective motor skill development throughout childhood and adolescence (Janacsek, Fiser, & Nemeth, 2012).

A key factor in children's motor learning is the development of foundational movement skills (FMS) (Hulteen, Morgan, Barnett, Stodden, & Lubans, 2018; Stodden et al., 2008). FMS are broadly identified as basic learnt motor patterns which include, locomotion skills (e.g., running and swimming); object control skills (e.g., throwing and catching a ball) and stability skills (e.g. balancing) (Gallahue, Ozmun, & Goodway, 2012). The development of FMS competence throughout childhood and adolescents is a critical precondition for participation in physical activity across the lifespan (Bolger et al., 2019; Lubans, Morgan, Cliff, Barnett, & Okely, 2010; Peers, Issartel, Behan, O'Connor, & Belton, 2020). Failing to develop FMS competence has been linked with physical inactivity; the fourth leading risk factor for global mortality from non-communicable diseases (World Health Organisation, 2014). However, a decline in FMS competence over the past few decades has highlighted the need to optimise FMS interventions and motor learning settings (e.g., physical education) through effective instruction and feedback (Bardid, Rudd, Lenoir, Polman, & Barnett, 2015; Foulkes et al., 2015; Tester, Ackland, & Houghton, 2014). Morgan et al., (2013) highlight that physical education is an effective setting to directly develop FMS, where physical education teachers engage children in the motor learning process through instructional approaches (Gurvitch & Metzler, 2010). However, physical education has become progressively marginalised within school settings and is typically perceived as low priority in contrast to core subjects (e.g., mathematics) (Bailey, 2018). Therefore, if the time dedicated to physical education is limited (Bailey, 2018) then the application of the OPTIMAL model could be critical in optimising instructional approaches to enhance children's motor learning in physical education settings (Krajenbrink, van Abswoude, Vermeulen, van Cappellen, & Steenberg, 2018; Hiller, 2007). Additionally, given the recent call to underpin the physical education curriculum with strong theoretical support (Rudd, O'Callaghan, & Williams, 2019), it would appear timely to examine how an EF, EE and AS impact children's motor learning to optimise FMS interventions for potential use in physical education and other motor learning settings.

Therefore, the aim of this systematic review was to examine the existing research addressing how individual and combined OPTIMAL factors impact children's motor performance and learning with reference to FMS. The review also aims to explore the potential mediators and moderators specific to children's motor performance and learning based on OPTIMAL theory predictions (Wulf & Lewthwaite, 2016). Critically for this population, we will examine how children's different developmental characteristics may impact the effectiveness of OPTIMAL components in motor learning environments (Gallahue et al., 2012), or provide important considerations for its future application in this nascent field of work.

2. Methods

2.1 Eligibility criteria and information sources

A detailed, systematic search of literature was conducted to obtain all relevant studies concerning an EF, EE and AS with child populations. The systematic review was conducted using PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analysis; Moher, Liberati, Tetzlaff, & Altman, 2009) guidelines. Using the general key words: "*children*", "*adolescents*", "*motor learning*", "*motor performance*"; combined with specific key words: "*external focus of attention*", "*enhanced expectancies*", and "*autonomy support*", a computer-generated search was conducted in the EBSCO, Google scholar, PubMed and Web of Science databases. In addition, the reference lists of all relevant journal articles and review articles were searched to ensure all relevant research was obtained.

In summary, three separate searches were conducted in November 2019. Studies were considered for inclusion if: they were presented as peer reviewed full text journal articles; were written in English; included school aged children and adolescents (5-16 yrs); examined children's FMS in a sport and/or exercise setting and manipulated an OPTIMAL variable (e.g. directed focus externally). To ensure the most rigorous and contemporary literature was collected, the search process included all published work from January 1994 – November 2019. For clarity, studies were excluded if: they were not presented as full text journal articles (e.g., unpublished data, conference abstracts); they were not peer reviewed; were not written in English; the publication date was before January 1994 or after November 2019; did not examine FMS or did not manipulate an OPTIMAL variable.

2.2 Search Process: Study and data selection

In the combined search, 2645 records were excluded in the screening phase. A total of 432 full-text articles were assessed for eligibility by each author (TS, PE, EC, DM) collectively. Through this process 377 full-text studies were excluded resulting in 55 eligible studies (see figure 1 for overview). A breakdown of each search (i.e., EF, EE, AS) is presented next. For "*external focus of attention*"; 2,632 records were identified. After screening abstracts, removing duplicates and eliminating studies that did not meet the criteria, 296 full text studies were searched revealing that 35 were eligible for review. “*Enhanced expectancies*” search returned 197 results. A title and abstract screening and full text search (n = 62) eliminated 189 studies that were duplicates or did not manipulate participants performance expectancies and did not examine children resulting in a total of 12 studies eligible for review. Seven-hundred and eighteen studies (718) for “*autonomy support*” were searched (74 full-text) leading to an exclusion of 711 studies for reasons including duplications, no autonomy support element or did not examine child populations; overall eight studies were eligible for review. In total the combined search highlighted 55 eligible studies (EF = 35, EE = 12, AS = 8).

[Figure 1 near here]

3.0 Results

The results of the systematic review revealed that 71% of studies (n = 39) included in the final analysis, supported the application of OPTIMAL variables to enhance children’s motor performance and learning. However, 29% of studies (n = 16) failed to find a benefit of an EF (n = 14), EE (n = 1) and AS (n = 1) highlighting a requirement for methodological considerations (e.g., delivery characteristics and content of attentional focus instructions) for research with children. An overview of studies is presented in table 1 (EF), table 2 (EE) and table 3 (AS). A summary of instructions used in EF studies are highlighted in table 4, revealing some conceptual and methodological issues with instructional sets. Additionally, the search highlighted that the provision of choice was the primary manipulation of AS with alternate approaches unexplored to-date (e.g., providing rationale; Su & Reeve, 2011). The combined search highlighted a skewness towards object manipulation skills (36 studies), whilst research on locomotion (11 studies) and stability skills (8 studies) is comparatively lacking. Furthermore, hand throwing skills are favoured within object manipulation skills thereby reducing the generalisability of OPTIMAL approaches across this skill set that also includes catching and kicking. Despite the proposed interactive benefits of OPTIMAL factors, only 2 studies explored and reported the positive combinatory effects on children's motor learning. These studies combined AS and EE, and EF and AS respectively, leaving some double combinations and approaches unexplored. No studies explored the combined effects of all three OPTIMAL components despite greater learning enhancements observed in adult populations (Wulf, Lewthwaite et al., 2018). Additionally, nine studies examined the impacts of OPTIMAL variables on children with developmental disorders further highlighting a gap in the research. Due to the high variability in children's developmental characteristics (e.g. age, maturation) the review will focus on understanding the potential mediators and moderators influencing children's motor performance from an OPTIMAL theory perspective.

3.1 External focus of attention

As observed in adult populations, the benefits of an EF extend into child populations with 60% (n = 21) of studies reporting beneficial effects on motor learning compared with an IF and/or no instructed focus (Table 1) (Wulf, 2013). These benefits have been reported across the full FMS range, although object manipulation skills are over-represented (n = 23) in comparison to locomotion (n = 7) and stability skills (n = 4). However, in comparison to adult populations there is a substantial body of work which has failed to find an EF benefit on motor performance and learning (n = 14). An examination of the research has highlighted that developmental factors, task constraints and attentional focus conceptions may have a potential moderating role of the EF effect.

[Table 1 near here]

3.1.1 Developmental factors and task constraints

The review indicates that children's different developmental characteristics may moderate the attentional focus effect on motor learning. First, children are limited in their comprehension and processing capacities as compared to adults (Liu & Jensen, 2011). Therefore, overly detailed and complex instructions may explain why some studies failed to find a benefit of an EF (e.g., Fathi Khatab, Ghasemi, & Mousavi Sadati, 2018; Tse, 2019). Buszard et al., (2017) stated that complex and detailed instructions negatively impact children's motor performance by overloading their relatively limited working memory capacity. In contrast, concise EF instructions have enhanced motor performance and learning across the full FMS range, presumably due to their limited impact on attentional resources in comparison to an IF (e.g., Bodasinska, Zielinski, & Makaruk, 2019; Chiviacowsky, Wulf, & Ávila, 2013; Fathi Khatab et al., 2018; Kal, van der Kamp, & Houdijk, 2013; Marchant, Griffiths, Partridge, Belsley, & Porter, 2018; Wulf, 2013). However, Patranek, Bolter and Bell (2019) found that concise IF feedback (e.g., arms out wide), when delivered intermittently, enhanced movement form when learning an overhand throw in comparison to EF feedback (e.g., make a "*T*"; table 4). The authors suggested that the IF feedback may have been more comprehendible for young children (aged 6-7 yrs) to understand due to their limited encoding strategies and their tendencies to address the literal meaning of the instruction being presented (Corbin, Reyna, Weldon, & Brainerd, 2015), for example, *"bring you throwing hand past your ear"*. However, older and more experienced children are better able to extract subjective meanings of instructions to interpret cues in a way that make sense to them (Boulenger, Hauk, & Pulvermuller, 2009; Guan, Meng, Yao, & Glenberg, 2013; Reyna & Brainerd, 2011). Agar, Humphries, Naquin, Herbert and Wood (2016) support this point demonstrating that older children (9-12yrs) performed consistently better than younger children (5-8yrs) in a shuffleboard task regardless of attentional focus instruction (which themselves did not impact learning). This suggests that developmental cognitive differences may impact the processing of attentional instructional cues which in turn may impact movement mechanics (Patranek et al., 2019). However, IF instructions are generally more demanding on working memory and can be detrimental to motor learning in adults (Kal et al., 2013; Masters & Maxwell, 2008; Poolton, Masters, Maxwell, & Rabb, 2006). In children, verbal working memory capacity did not predict performance in 8-12-year-old children despite an EF enhancing motor performance (Brocken, Kal, & Van der Kamp, 2016). This indicates that children’s verbal working memory has not matured enough to effectively translate working memory demanding IF instructions into a motor response (Vogan, Morgan, Powell, Smith, & Taylor, 2016). However, Brocken et al. (2016) identified that their sample displayed a relatively high working memory capacity for children which may have nullified the detrimental effects of an IF. In addition, they did not assess visuo-spatial working memory, despite its importance to motor skill learning (Seidler, Bo, & Anguera, 2012). Conversely, visuo-spatial working memory, but not verbal working memory, also moderates EF advantages (Van Cappellen-Van Maldegem, Van Abswoude, Krajenbrink, & Steenberg, 2018) yet pre-test throwing accuracy differences between EF and IF groups may have limited exploration of attentional focus effects in children with DCD. Van Cappellen-Van Maldegem et al. (2018) hypothesise that children use visuo-spatial working memory to translate spatial coordinates and kinematic information about the movement and goal into actual motor performance (Quinn, 2008), yet this effect may be task-dependent. In other work, neither verbal or visuo-spatial working memory capacity influenced children’s motor learning or the impact of EF and IF instruction (Van Abswoude, Nuijen, Van der Kamp & Steenbergen, 2018). Moreover, it should be considered that Automated Working Memory Assessment (AWMA) may not be sensitive enough to test children’s working memory capacity (Brocken et al., 2016; Krajenbrink et al., 2018; Van Abswoude et al., 2018; Van Cappellen-Van Maldegem et al., 2018). Despite these mixed findings, given the importance of visuo-spatial and verbal working memory capacity to motor learning and motor skill instruction comprehension (e.g., Buszard, et al., 2017), and its developmental sensitivity (Oberauer, Farrell, Jarrold, & Lewandowsky, 2016), the role of working memory in effective instructional approaches for children requires further consideration within the OPTIMAL framework.

[Table 4 near here]

Regardless of the impact of attentional cues on motor learning and working memory some research indicates that the EF benefit may be moderated by individual preference. For example, Tse and Van Ginneken (2017) found that 10-year-old children with high conscious motor control propensities performed a dart throwing task better under IF conditions whereas children with low conscious motor control propensities benefited from an EF. Additionally, Van Abswoude et al. (2018) reported that children performed better when attentional focus instructions matched their focus preference. Whilst these findings do not support predictions of the constrained action hypothesis (Wulf, McNevin, & Shea, 2001), some children may prefer to adopt an IF due to a prominent bias of internally focused instructions in physical education settings (Fronske & Wilson, 2002; McNamara, Becker, & Silliman-French, 2017). However, Van Abswoude et al. (2018) measured focus preference by asking children which instructional set required more effort. Whilst this may not directly measure preference, it suggests that preference may be influenced by a child’s comprehension and indeed working memory capacity (e.g., whichever instructions are easier to comprehend and interpret). Therefore, it appears the EF benefit is moderated by children’s comprehension, preference and cognition (Marchant, Griffiths, et al., 2018; Maurer & Munzert, 2013; Patranek et al., 2019). Despite emerging evidence of developmental considerations for children’s motor learning and attentional focusing, more work is required to understand the mechanisms underpinning the EF impact and their application into physical education and motor learning settings.

The benefits of an EF versus an IF are explained through the constrained action hypothesis which explains that an EF promotes automatic, unconscious and reflexive motor control by increasing functional movement variability and reducing attentional demands (Kal et al., 2013; Lohse et al., 2014; Wulf et al., 2001). Whilst some studies with children supported predictions of the constrained action hypothesis (table 1), Patranek et al. (2019) argues that the constrained action hypothesis does not make predictions regarding age or developmental status making it difficult to extend the hypothesis to young children (aged 6-7 yrs). Additionally, Shin, Kim and Lee (2012) explain that children aged 8-12-years old are in a critical development phase of the kinaesthetic system and therefore an IF may be more effective until the motor system becomes more automatic (Fathi Khatab et al., 2018). The exploration of the attentional focus effect is further limited by a lack of consideration for the high variability of children’s motor skills throughout this critical period of motor development driven by gender, experimental and developmental variables (Becker & Smith, 2013; Flores, Menezes, & Katzer 2016; Patranek et al, 2019; Thomas, 2000). Further complexity is added when considering the range of motor tasks explored. For example, in jumping tasks an EF has proven effective for standing long jump performance (Chow et al., 2014) especially when a more distal EF is promoted (e.g., a focus further from the body; Marchant, Griffiths et al., 2019). However, in some throwing tasks an IF has been reported to enhance performance by helping to develop skill fundamentals (e.g., Fathi Khatab et al., 2018). Therefore, the difference in movement mechanics (e.g., gross vs fine motor skills) may moderate the EF advantage. For example, whilst an IF improved dart throwing performance (fine motor skill) (Fathi Khatab et al., 2018), Kranjenbrink et al. (2018) found that an EF improved performance of a slingerball throwing task (gross motor skill) (Gallahue et al., 2012). Furthermore, the target size may have further influenced movement mechanics and the EF effect. For example, throwing at a 1cm wide-target (i.e., bullseye of a dartboard) requires greater precision than throwing at a 12.5cm target (Kranjenbrink et al., 2018) and could therefore result in greater movement variability to select the correct motor response (Ong, Hawke, & Hodges, 2019). Whilst an IF may aid precision by freezing degrees of motor freedom (e.g., reducing movement variability); in general, an IF is detrimental to motor learning (e.g., movement reinvestment; Masters & Maxwell 2008; Poolton et al., 2006). Additionally, reducing movement variability may be detrimental to children's motor learning and FMS development as it reduces opportunities to develop an extensive motor repertoire (i.e., reduced movement solutions) (Whitehead, 2010). According to ecological dynamics, exploration of movement solutions through goal directed behaviour is critical to create affordances that allow the learner to exploit the environment and overcome movement problems given the functional capabilities of the individual (Chow, Davids, Hristovski, Araujo, & Passos, 2011). Therefore, attentional focus may be a continuum where the optimal "*focus distance*" is dictated by children's developmental characteristics and task constraints. Wulf and Su (2007) explain that such "*distance of focus*" considerations activate different "*hierarchical*" mechanisms depending on the level of skill development. For example, in the early stages of motor learning a proximal-EF (i.e., an EF closer to body) can promote salient information - like that of an IF instruction - to younger/inexperienced children to help better develop basic skill technique (e.g., a focus of golf club movement) (Wulf, McNevin, Fuchs, Ritter, & Toole, 2000). Through skill development and maturation, a more distal-EF (e.g., a focus on the target or golf ball) could elicit children's motor automaticity (Wulf & Su, 2007). Therefore, task designs and verbal instruction which allow children to adopt various external foci (e.g., throwing tasks with different objects and target sizes) can afford the learner opportunities to develop adaptive movement solutions and thus increase movement competence to enhance the ability to exploit affordances to achieve future task success (i.e., enhance expectancies for successful performance) (Seifert & Davids, 2017; Simpson, Cronin, Ellison, Carnegie, & Marchant, 2020). In addition to the EF distance effect, Marchant, Griffiths et al. (2018) explain that pairing distal-EF instructions with visual cues (i.e., a cone to jump towards) can emphasise the task goal and increase the perceived attainability of the movement goal (e.g., enhanced expectancies for successful performance; Coker, 2016; Wulf & Lewthwaite, 2016). If children are limited in cognitive capacity and comprehension (Agar et al., 2016; Buszard et al., 2017) and tend to rely on visual coding (Cadopi, Chatillon, & Brady, 1995; Guilbert, Alamargot, & Morin, 2019), then a visual target becomes a useful external cue to enhance goal-action coupling, invite affordances and promote movement exploration (Chow et al, 2011; Seifert & Davids, 2017; Withagen, Araújo, & de Poel 2017). Such findings suggest that attentional and motivational aspects of instruction are not necessarily separate characteristics (Simpson et al., 2020). Yet, if visual cues are not representative of the performance environment then transferability of the benefits is reduced (Renshaw et al., 2019). In addition, it is important to recognise that an EF is not restricted to the use of visual cues (Abdollahipour, Land, Cereser, & Chiviacowsky, 2019; McNamara, Becker, Weigel, Marcy, & Haegele, 2019) suggesting that the clarity and relevance of EF instruction may also greatly contribute to effective goal-action coupling (e.g., Petranek et al., 2019; Russell, Porter, & Campbell, 2014). Physical education teachers and sports coaches should factor children's developmental characteristics and task constrains to select an appropriate attentional focus distance and consider the use of external visual cuing.

3.1.2 Instruction problems

The comparison of attentional focus studies is complicated by the framing and conceptualisation of attentional focus instructions in children's research (table 4). For example, some studies provide detailed and lengthy instructions which sometimes promote different task information (e.g., Fathi Khatab et al., 2018; Li, Li, Chu, Pan, & Chen, 2019; Schwab, Rein, & Memmert, 2019) whilst others provide short instruction sets which focus attention to a single aspect of the task (e.g., McNamara et al., 2017). Given children’s limited comprehension in comparison to adults, such differences in instructional sets could have dramatic impacts on the effectiveness of attentional focus manipulations (Buszard et al., 2017). Moreover, some studies frame instructions through direct quotes (e.g., Bodasinska et al., 2018) whilst others do not (e.g., Ashraf, Aghdasi, & Sayyah, 2017), leading to speculation that delivery characteristics may have varied between participants potentially confounding any focus of attention effect. Furthermore, some instructional sets promote visual information in one condition but not the other by highlighting the task goal with a visual cue (Coker, 2018; Marchant, Griffiths et al., 2018, Tse, 2019). Therefore, any differences between conditions cannot be solely attributed to the focus of attention instructions. Additionally, instructional cues do not always isolate or focus attention in the desired direction (see table 4). For example, Saemi, Porter, Wulf, Ghotbi-Varzaneh and Bakhtiari (2013) promoted the hand in the EF condition and the target in the IF condition (table 4), therefore it is impossible to accurately report how the focus of attention instructions effected motor performance (Wulf, 2013). Even when attention is focused in the desired direction the instructions do not always promote the most relevant task information or the intended movement outcome. For example, Perreault and French (2016) instructed children to focus on generating backspin on the ball, yet a focus on the rim of the basket may have better represented the intended movement effect linked to the task (i.e., score a basket) (Perreault & French, 2015; cf. Wulf et al., 2000). Likewise, temporal considerations point to focusing attention towards the intended movement effects being critical compared to effects occurring post-skill execution (Pourazar, Mirakhori, Bagherzadeh, & Hemayattalab, 2017;

Tse & Van Ginneken, 2017; Wulf et al., 2001). For example, whilst directing attention away from the self, focusing on the flight path of an implement (e.g., "*focus on the darts flight path*") does not explicitly state when to focus attention (i.e., during preparation or execution) nor does it clearly identify a specific intended movement effect (e.g., Tse & van Ginneken, 2017). In line with the constrained action hypothesis, providing children with temporally specific EF instructions which promote a clear movement effect/outcome throughout movement execution will be most optimal for their motor performance (Patranek et al., 2019) (e.g., "*focus on landing the dart in the bullseye when you throw*"). Similarly, it can be argued that metaphorical instructions are not aligned with attentional focus conceptions as they promote motor imagery (e.g., Van Abswoude et al., 2018), which have been suggested to help promote an external focus of attention (Wulf & Lewthwaite, 2016). Indeed, metaphorical instructions are effective for supporting children's motor learning (Chatzopoulos, Foka, Doganis, Lykesas, & Nikodelis, 2020), although comprehension is again a critical consideration (Boulenger et al., 2009; Boulenger, Shtyrov, & Pulvermüller, 2012). Whilst the above factors may nullify the detrimental effects of an IF they also potentially confound the benefits of an EF. When contextualised with the complexity of children's developmental characteristics, it becomes clear that directing attention via verbal instructions can have a great and varied impact on children's motor learning. Future research needs to carefully consider how attentional focus instructions are framed within children's research to more accurately report their effects on motor learning and performance.

[Table 2 near here]

3.1.3 Summary: external focus of attention

An EF is an important factor in optimising children's motor performance and learning. However, the EF effect appears to be moderated by children's developmental characteristics (e.g., age, comprehension, working memory) as there is substantial body of work unsupportive to the EF advantage in child populations to-date (table 1). Additionally, several methodological issues regarding the instructional approaches have made cross-study comparisons difficult (e.g., Agar et al., 2016; Fathi Khatab et al., 2017; Van Cappellen-Van Magldegem et al., 2018). However, it appears that concise, comprehendible and task-relevant EF instructions which highlight visual cues are most effective to children’s motor learning. Yet the optimal “*focus distance*” can vary along a continuum depending on developmental status, task constraints and task experience. Future research should continue to investigate how an EF and the distance effect interacts with children’s developmental characteristics to enhance motor learning interventions; but researchers should ensure that instructional cues are aligned with conceptions of attentional focusing (Wulf, 2013).

3.2 Motivation

3.2.1 Enhanced expectancies

The present review highlights that the dominant approach in children’s research is to enhance expectancies through feedback (table 2). These approaches have proven beneficial to children’s motor learning yet only 12 studies have examined EE on children’s FMS. Additionally, self-efficacy, perceived competence and positive affect appear to be key mediators of motor performance and learning (see Wulf & Lewthwaite, 2016 for review) although not measured in all studies. For example, Goncalves et al. (2018) examined positive social comparative feedback on the learning of a basketball free throw task and intrinsic aspects of motivation. Children who believed their performance was 20% better than their peers, improved performance in practice and transfer tasks. Additionally, compared to a control group, EE improved perceived competence, importance of task success and task persistence, and thereby enhanced positive affect and self-efficacy supporting predictions of the OPTIMAL theory (Deci & Ryan, 2000; Peers et al., 2020; Wulf & Lewthwaite, 2016). Likewise, bogus positive social comparative feedback provided during practice improved throwing accuracy and perceived competence in a retention test for 10-year-old children (Avila, Chiviacowsky, Wulf, & Lewthwaite, 2012). Whilst these studies highlight the impact of positive feedback, the use of bogus or false feedback is highly deceptive and should not be used in applied settings where vulnerable populations are present (i.e., children). Moreover, deceptive approaches may be less effective in physical education settings as compared to other EE approaches (e.g., framing conceptions of ability) given the ever-present nature of social comparison. Yet, they do stress the critical role that feedback, and positive comparative opportunities play in motor learning environments. For example, unlike typical experimental designs, physical education involves children learning motor skills in large groups enabling ample opportunity for social comparison (Butler, 1998). Therefore, if social comparison from a teacher contradicts the child’s self-assessed social comparison (i.e., comparing performance with a peer) performance expectancies could be diminished through decreased perceived competence, intrinsic motivation and could create distrust between teacher and child. Motor learning settings that are sensitive to such comparisons should help foster motor skill learning in lower ability children. In contrast to social comparison approaches, regulating knowledge of results via feedback may be a more suitable approach to impact children’s motor learning through EE. For example, providing feedback on good rather than poor trials improved throwing performance in 10-year-old children (Saemi, Wulf, Varzaneh, & Zarghami 2011). In addition, children in the “*good-trials*” condition reported higher perceived competence, effort, and task importance suggesting that positive self-performance feedback has motivational effects on motor learning (Saemi et al., 2011). Therefore, providing knowledge of results on “*good-trials*” can elicit the motivational and learning benefits of positive false-social comparison without the need for deception; and can provide individualised feedback to optimise the motor learning environment. Nevertheless, the impact of social comparison and knowledge of "*good*" results has only been demonstrated in object control skills to-date and requires further work across a range of skills. However, evidence indicates it is important to consider how instructions and feedback are worded in teaching and learning contexts to support optimal enhancement of performance expectancies.

[Table 2 near here]

As an alternative to impact EE through results-based feedback, Chiviacowsky and Drews (2014) manipulated conceptions of ability using feedback statements in a soccer kicking task. In the first acquisition phase, children received positive feedback implying that the task was malleable and could be developed through practice (e.g. "*those kicks were very good*") or received feedback that suggested performance reflected their inherent ability (talent) (e.g. "*you have a talent for soccer*"). In the second acquisition phase, negative feedback was given on each trial (e.g. "*those kicks were not very precise*"). After receiving negative feedback, participants in the talent condition demonstrated degraded kicking accuracy relative to the malleable condition (Chiviacowsky & Drews 2014). Furthermore, a second experiment (a throwing task) found that inherent-ability feedback (e.g. "*you have a talent for throwing*") may have a lasting detrimental effect on a child's intrinsic motivation (e.g., self-efficacy) via decreased perceptions of competence (Peers et al., 2020; Dweck, 2002). That is, feedback about inherent ability in the event of a setback can be perceived as a threat and can reduce perceptions of competence resulting in avoidance behaviours (i.e., reduced physical activity) (Chiviacowsky & Drews 2014; Nicholls, 1984). In contrast, suggesting that performance is malleable has the potential to increase task effort after errors through EE for future success (Hutchinson, Sherman, Martinovic, & Tenenbaum, 2008). Yet, cautious interpretation is required as Chiviacowsky and Drews (2014) did not directly measure the motivational effects of their feedback. Nevertheless, this study shows that children are sensitive to how ability is framed within practice environments and the potential long-term impact on children’s motor learning (Chiviacowsky & Drews, 2014; Peers et al., 2020).

In addition, positive self-modelling can also augment motor learning through EE. Clark and Ste-Marie (2007) demonstrated that positive self-observation via video feedback enhanced swimming performance, self-efficacy, self-observation and intrinsic motivation as compared to a control group (see also Zetou, Kourtesis, Getsiou, Michalopoulou, & Kioumourtzoglou, 2008). However, Ste-Marie, Vertes, Rymal and Martini (2011) reported that whilst positive self-observation enhanced the learning of a trampoline routine, performance improvements could not be explained by changes in intrinsic motivation or self-efficacy. Likewise, Law and Ste-Marie (2005) observed no benefit of positive self-modelling on performance in comparison to a physical practice-only condition in a figure skating task, indicating that the benefits of self-observation may be moderated by self-perceptions of performance and individual characteristics. However, Law and Ste-Marie’s (2005) results indicated that children perceived the intervention as “*very positive*” suggesting that the intervention likely had a positive effect on motivation, however the study lacked the sufficient statistical power required to observe meaningful differences. Nonetheless, the findings potentially show that the effects of EE may extend to more experienced and competent child populations (i.e., intermediate figure skaters) highlighting the need for further research in this under-represented population. Overall, these studies show that the benefits of positive self-modelling may be mediated by motivation and children’s cognitive abilities.

Beyond the use of feedback to enhance expectancies, perceptions for success can be improved through setting of appropriate performance criteria. For example, defining success by using large (easier) target zones has improved adult’s motor learning (golf putting accuracy) as compared to smaller target zones which increased perceived task difficulty (Palmer, Chiviacowsky, & Wulf, 2016). This approach impacts EE through both pre-task expectations and framing post-task feedback. However, this method is under-represented in children’s research. Bahmani, Wulf, Ghadiri, Karimi and Lewthwaite (2017) used optical illusions to alter the perceived target size in a golf putting task. Their findings replicated the effect observed in adults (Palmer et al., 2016) as a perceived larger target improved putting accuracy throughout practice and retention (without illusion) in comparison to a perceived smaller target. Moreover, a relationship between perceived target size and self-efficacy suggested that perceptions of success were mediated through performance expectations, supporting predictions of the OPTIMAL theory (Wulf & Lewthwaite, 2016). Additionally, increased self-efficacy has been linked with a reduction in self-focused attention indicating that implicit manipulations, which increase the likelihood for successful performance, could indirectly promote an EF (Marchant, Carnegie et al., 2018; Marchant, Griffiths et al., 2018; McKay, Wulf, Lewthwaite, & Nordin, 2015; Pascua, Wulf, & Lewthwaite, 2015; Stevens, Anderson, O’Dwyer, & Williams, 2012). Obviously, the use of visual illusions is not practical in applied settings, however increasing perceptions of success through other implicit manipulations could be effective to enhance motivation and motor learning for children (e.g., Capio, Poolton, Sit, Holmstrom, & Masters, 2013). This line of research has implications for task design in physical education and motor learning settings. For example, altering implicit success manipulations (i.e., the size of a throwing target) allows physical educators and sports coaches to scale the environment to afford engagement in goal-directed behaviour based on an individual’s capabilities (Chow et al., 2011). In other words, task difficulty can be adapted to challenge the individual to explore new movement patterns whilst ensuring they remain motivated and engaged with the task. Future research should examine how implicit manipulations effect motivation and attentional focusing in children’s motor learning and how these manipulations can be used in physical education settings.

3.2.1.1 Factors influencing enhanced expectancies

The benefits of positive social comparative feedback may be moderated by developmental characteristics. For example, Drews, Chivacowsky and Wulf (2013) investigated conceptions of ability in 6, 10 and 14-year-old children completing a beanbag throwing task under inherent (“*aiming is an ability that you are born with*”) and malleable (“*aiming is a skill that can be learned*”) conditions. The malleable group demonstrated better motor learning than their counterparts, suggesting that EE increased self-efficacy, positive self-evaluation, and reduced nervousness and self-focusing (Drews et al., 2013). Additionally, the performance for 14-year-old children in the inherent group was significantly poorer than that of younger children. One explanation is that this age group’s heightened sense of social comparison and increased intensity of self-conscious emotions (Zeman, Cassano, Perry-Parrish, & Stegall, 2006), left them vulnerable to potential threats to the self (e.g. their inherent ability) (Drews et al. 2013) which is likely to induce an IF (McKay et al., 2015; Pascua et al., 2015). In contrast, younger children are more influenced by temporal comparisons rather than social comparisons (Dweck, 2002) but can still benefit from positive social comparisons (Avila et al., 2012; Butler, 1998). Although the methods used for social comparisons may not be suitable for applied settings, recognising its positive impact on children’s perceived competence is critical considering the mediating role of perceived competence on children’s engagement in physical activity (Bardid et al., 2017). Future research and physical educators should consider the role of children’s developmental characteristics when attempting to enhance expectancies.

Differences in motor abilities and task constraints also appears to moderate the effects of EE in children. A study by Capio, Poolton, Sit, Holstrom et al. (2013) manipulated task constraints to alter perceptions of error in a throwing task. Reducing perceptions of error and opportunity for error by progressing from smaller to larger targets, improved motor learning as evidenced by enhanced movement form, throwing accuracy and dual-task performance (counting backwards from 100) (Capio, Poolton, Sit, Holstrom et al. 2013). Although not directly measured, the authors suggest that errorless learning facilitates greater experiences of success and enhances expectancies through increased self-efficacy (Bandura, 1977; Pascua et al., 2015). Importantly, reducing practice errors significantly improved throwing accuracy in children with low motor abilities. Whilst higher ability children did not exhibit enhanced motor learning, the task may not have generated sufficient challenge to avoid boredom (Capio, Poolton, Sit, Holstrom et al., 2013) highlighting the need to differentiate practice schedules based on ability. Furthermore, girls’ movement form was significantly improved from baseline but not for boys. This is likely due to boys displaying greater object control skill competency as compared to girls (Foulkes et al., 2016). Differences in “*play*” may explain FMS gender differences as boys in comparison to girls are more likely to engage in physical activity with ball use (e.g., football) as a result of social influences (Butterfield, Angell, & Mason, 2012). Additionally, Capio, Poolton, Sit, Holstrom et al. (2013) failed to find an interaction between gender and practice group (i.e., error reduction and error strewn) indicating the need for caution when interpreting the impact of interventions on girls’ object-control skills. Nevertheless, error-reduction interventions appear to be an effective method to enhance performance expectancies through perceptions of competence. Research has highlighted that regardless of actual motor competence, a high perceived competence in young children is a critical factor to improve motivation for engagement in physical activity (Bardid et al., 2016; Bolger et al., 2019; Pesce, Masci, Marchetti, Vannozzi, & Schmidt, 2018; cf. McIntyre, Parker, Chivers, & Hands, 2018). Therefore, enhancing expectancies for success through implicit manipulations could be vital to engage and sustain children in the motor learning process (Bahmani et al., 2018; Bolger et al., 2019). Developmental factors such as prior experience, skill level, age and gender should be accounted for when enhancing expectancies for children's motor learning.

3.2.1.2 Summary: enhanced expectancies

There is growing evidence that enhancing expectations for successful performance is beneficial to children's motor learning. Evidence advocates that (false) social comparative feedback; framing conceptions of ability; increasing opportunities for success through implicit manipulation and providing feedback after good trials are effective methods to support children's motor learning. However, the use of deception (i.e., false-positive social comparative feedback) is strongly discouraged in applied settings especially when working with vulnerable populations like children, where such efforts can be undermined by comparative experiences. Additionally, enhancing expectancies has demonstrated to improve self-efficacy, perceived competence and positive affect, yet the measurement of motivation is limited within children's EE research (table 2). The motivational and learning advantages of EE appear to be moderated by children's age, gender and ability level. This highlights a requirement for physical education teachers and sports coaches to tailor feedback and practice based on children's developmental characteristics. However, in comparison to adults there are numerous EE approaches yet to be explored within child populations (e.g., combining social comparison and conceptions of ability; Wulf, Lewthwaite, & Hooyman, 2013). Future research should include motivational measures in future EE studies and factor developmental characteristics. Additionally, it appears that approaches to enhance expectancies can be used to promote an EF through implicit learning (i.e. errorless learning; Masters & Maxwell, 2008). Therefore, future studies should explore how motivational and attentional factors can be integrated to optimise children's motor learning (Simpson et al., 2020; Wulf & Lewthwaite, 2016).

3.2.2 Autonomy support

The benefits of AS were found in 85% of the studies reviewed (N = 7) yet compared to research with adult's, AS research with children is comparatively lacking (Table 3). Like adult populations, the primary approach to AS with children is the provision of choice (Sanli, Patterson, Bray, & Lee, 2013). Although the OPTIMAL theory primarily focuses on AS through provisions of self-controlled practice and the opportunity for choice (Wulf & Lewthwaite, 2016), perceptions of autonomy can also be impacted through the provision of a meaningful rationale; through consideration of an individual's feelings and perspectives; through motivational nurturing; and when non-controlling language is used (Su & Reeve, 2011). However, these approaches are limited in motor learning studies for all populations (Hooyman et al., 2014). In the physical education literature AS is considered a teaching style which can be developed through interventions (Su & Reeve, 2011). In fact, a recent meta-analysis indicated that an autonomy supportive teaching style can greatly improve a child's perception of autonomy, competence and increase their intrinsic motivation through more positive experiences in physical education (i.e., AS can enhance expectancies and increase physical activity levels and FMS competence) (Vasconcellos et al., 2019). Therefore, although limited and focused on the provisions of choice, the finding of the present review supports the use of AS in children's motor learning. Additionally, the present findings support a previous meta-analysis exploring AS in the form of choice (Patall, Cooper, &

Robinson, 2008), where choice was more effective to children’s learning and education in comparison to adults (Patall et al., 2008). The opportunity for choice had a more powerful effect on children as they are typically presented with limited opportunities to make active choices, thereby heightening their limited sense of autonomy. Additionally, choice enhanced perceived competence, task effort, and intrinsic motivation; key mechanisms within OPTIMAL theory (Wulf & Lewthwaite, 2016). Although Patall et al.’s meta-analysis did not specifically focus on motor learning, it provides a valuable developmental perspective into the impact of AS on children’s learning.

[Table 3 near here]

When considering the generation of autonomy in the preparation for motor skill learning, it is important to consider the skill learning process. Schmidt, Lee, Winstein, Wulf and Zelaznik (2019, p. 375) explain that a learner gathers task-relevant knowledge about a skill to maximise learning potential. Therefore, skill demonstrations are ideal to communicate skill knowledge to a novice learner, and when combined with AS; enhance the motor learning environment (Wulf, Lewthwaite et al., 2018). For example, choice of when to view video demonstrations of an expert model, improved ballet performance in 10-year-old children alongside self-efficacy, positive affect, and task focus (Lemos et al., 2017; Stoate et al., 2012). In comparison, a yoked-group reported more self-related and negative thoughts during practice, thereby limiting goal-action coupling (McKay et al., 2015). This demonstrates that positive motivational factors underpinning choice driven AS also apply to children’s motor learning, in line with the observations made by Patall et al. (2008).

Autonomy has also been supported with regards to the feedback children receive once their learning efforts are completed (Huber, 2018). The present review highlights that 75% (N

= 6) of studies allowed self-regulation of feedback frequencies as the primary approach to implementing AS. It appears that in motor learning settings, the benefit from the opportunity to decide when to receive feedback generalizes to children's motor learning. For example, 10-year-old children learnt a beanbag throwing task more effectively when feedback was requested more frequently. Even when feedback is requested at a less than-optimal-rate, the opportunity for choice (i.e., autonomy support) enhanced motor learning, potentially due to increased intrinsic forms of motivation (Chiviacowsky, de medeiros, Kaefer, Wally, & Wulf, 2008; Chiviacowsky, Wulf, de medeiros, Kaefer, & Tani 2008; Goudini, Ashrafpoornavaee, & Farsi, 2019). Notably, adults exposed to similar feedback protocols did not differ in their learning (Chiviacowsky, Godinho, & Tani, 2005), suggesting potential developmental influences where children are particularly sensitive to the role of choice and feedback (Patall et al., 2008). Additionally (replicating effects observed in adults) children also requested feedback mainly after good trials, suggesting that self-selected positive feedback supported the use of intrinsic feedback to evaluate performance and an awareness that knowledge of results after poor trials was less important. Furthermore, self-controlled feedback allowed practice to be tailored to individual needs by potentially promoting augmented information processing (e.g. error detection and correction) (Carter & Ste-Marie, 2017) through greater availability of dopamine for memory consolidation (Legault & Inzlitch, 2013; Schultz, 2013).

Moreover, autonomy can be supported through provisions of augmented skill knowledge by receiving verbal and visual feedback on a child's learning efforts. In Ste-Marie, Carter, Law, Vertes and Smith (2016), children (aged 11) learning double-mini trampoline progressions could choose when to receive feedback in the form of video self-observation. The self-controlled group completed significantly more skill progressions than the yoked group at retention, supporting the benefits of self-selection on this mode of feedback in children (supporting earlier work by Ste-Marie, Vertes, Law, & Rymal, 2013).

However intrinsic motivation and self-efficacy did not mediate performance (Ste-Marie et al., 2016). It is possible that feedback which explained how to successfully complete each sequence elevated fear of punishment or feelings of disapproval from coaches. This may have hindered self-efficacy, nullified the benefits of AS and diminished performance expectations (Ste-Marie et al., 2016). A manipulation check regarding children's thoughts may have potentially captured this issue and confirmed the direction of attention promoted by the feedback statements. Additionally, the authors propose that augmented information processing explains the self-controlled practice benefits (Carter & Ste-Marie, 2017; Grand et al., 2015) however enhanced information processing is not a suitable alternative explanation (Goudini et al., 2019; Grand, Daou, Lohse, & Miller, 2017; Ikudome, Kou, Ogasa, Mori, & Nakamoto, 2019; Lemos et al., 2017; Ste-Marie et al., 2013). Instead there are likely numerous factors which mediate and moderate the effects of self-control (e.g., the timing of choice; Chiviacowsky & Wulf, 2005). Furthermore, the encompassing nature of motivation (i.e, the continuum form amotivation to intrinsic motivation) makes selecting the most appropriate motivational assessment difficult (Ryan & Deci, 2000; Ste-Marie et al., 2016). Additionally, motivational assessments typically require more statistical power than what is usually observed in motor learning studies (Grand et al., 2017; Lohse, Buchanan, & Miller, 2016) . Nevertheless, performance increased because of AS thereby supporting predictions of the OPTIMAL theory (Wulf & Lewthwaite, 2016).

Finally, alternative provisions of AS are yet to be explored across children's and indeed adult's motor learning studies (Sanli et al., 2013). For example, Su and Reeve (2011) identify that perceptions of autonomy are impacted when: the provision of a meaningful rationale is presented; an individual's feelings and perspectives are considered; motivational resources are nurtured and when non-controlling language is used. With regards to the latter, research is yet to consider the impact of autonomy supportive instructional language on children’s motor learning despite its beneficial effect on adults’ motivation and motor learning (Hooyman et al., 2014). However, given that instruction is a critical factor in motor learning research current AS work is yet to provide such context setting instruction in any detail (Table 3). Additionally, given the apparent link between AS and EF (Ste-Marie et al., 2012) it seems likely that autonomy supportive language could impact and could be integrated into EF instruction sets although the AS language alone may reduce a self-focus and aid memory consolidation (Ashby, Tuner, & Horvitz, 2010; Trempe & Porteau, 2012). Moreover, AS intervention training for physical educators, which include AS language and other provisions of AS (e.g., providing rationale), have demonstrated to improve student motivation, perceptions of autonomy and intentions to participate in physical activity (e.g., Cheon, Reeve, & Moon, 2012; How, Whipp, Dimmock, & Jackson, 2013; Raabe, Schmidt, Carl, & Honer, 2019). These studies demonstrate the effective use of teacher-training interventions to apply AS into ecologically valid settings, yet the assessment of their impact on motor learning is limited (Legrain, Gillet, Gernigon, & Lafreniere, 2015). Nevertheless, the OPTIMAL theory contends that conditions which support autonomy will enhance motor performance as compared to controlling or no-choice conditions (Wulf & Lewthwaite, 2016). Future research should explore the effects of different provisions of AS (e.g., supportive language) on children’s motor learning, its application into ecologically valid settings, and its potential interactive effects with other OPTIMAL variables (e.g., EF).

3.2.2.1 Mediators of autonomy support

The present review highlights that children’s different developmental characteristics may influence the effectiveness of AS approaches. For example (Bokums, Meira, Neiva, Oliveira, & Maia, 2012), feedback was requested more often after good trials by 12-14-year-old girls when learning an overhead volleyball serve (Chiviacowsky, de Medeiros et al., 2008; Chiviacowsky, Wulf et al., 2008). However, no performance benefits were observed indicating that the task may have been too difficult/complex for children/novices. Interestingly, they identified that highly anxious (trait anxiety) children requested feedback more frequently than low anxious children presumably to cope with task demands (Weinberg & Gould, 2018). This indicates that self-selected feedback (AS) may lower expectancies by highlighting poor performance in highly anxious children, consequently lowering self-efficacy, perceived competence and intrinsic motivation (Ziv et al., 2019). These findings suggest that AS and EE do not always interact as the motivational benefits of autonomy are not always observed. Another developmental observation is that children in general, when given the choice, request knowledge of performance feedback more regularly than adults. Ste-Marie et al. (2013) suggest that this may be due to children's greater need for information to assist them in interpreting intrinsic feedback (e.g., error correction), and key cognitive developmental differences such as speed of processing and working memory may mediate the effect (Surwillo, 1977; Thomas, 2000). Despite these suggestions research highlights that information processing may be driven, at least partially, through motivational mechanisms (Grand et al., 2017; Lewthwaite, Chiviacowsky, Drews, & Wulf, 2015; Wulf, Iwatsuki et al., 2018).

To date, several mechanisms have been proposed to explain the effects of choice driven AS. These are primarily centred on the motivation and information processing perspectives (Leiker, Pathania, Miller, & Lohse, 2019; Wulf & Lewthwaite, 2016). Although arguments are made in favour of both perspectives this is a false dichotomy. For example, research has demonstrated the benefits of both task-irrelevant and task-relevant choice on motor learning (Wulf, Iwatsuki et al., 2018). It is likely that task-relevant choices engage the learner in deeper information processing through active involvement in the learning process (Carter & Ste-Marie, 2017). However, it is unlikely that a task-irrelevant choice will promote a learner’s information processing, therefore any benefits on learning are likely the result of increased motivation (Graham & Golan, 1991; Lewthwaite et al., 2015 cf. Grand et al, 2017). Additionally, some research has highlighted that task-relevant choices (i.e., when to view video demonstrations) improve motivation (e.g., Lemos et al.,2017). Clearly, the benefits of AS in the form of self-controlled practice extend beyond a cognitive explanation (Patall et al., 2008). Indeed, the opportunity for choice creates rewarding conditions which may be a precursor for effective error-processing, reduced self-regulatory activity and keeping attention directed at the task goal (Legault & Inzlitch, 2013; Grand et al., 2015; Grand et al., 2017). Of course, there are numerous factors which will impact the effectiveness of choice, for example: initial motivation, choice variables, choice timing etc (e.g., Ikudome et al., 2019). What is considered rewarding/motivating for one individual may not be for another (Schultz, 2013) but nevertheless optimising motivational conditions through the opportunity for choice may be critical for optimal motor learning (Wulf, Iwatsuki et al., 2018). From a practical perspective simply supporting autonomy through the opportunity for choice (and other representations of AS) appears to be beneficial to motor learning. Perhaps offering both task-relevant and task irrelevant choices allows individuals to make a choice which is most beneficial to them based on their individual characteristics (e.g., motivation for the task). That is, an individual who is more motivated during practice may exhibit enhanced information/feedback processing (Ikudome et al., 2019; Grand et al., 2017). Specifically, in a physical education setting children constantly engage in information processing as they move around the environment (Rudd et al., 2019). Therefore, enhancing motivation through AS may enhance children’s information processing and error correction with potential benefits to motor learning (Grand et al., 2017; Legault & Inzlitch, 2013; Patall et al., 2013). Overall, whilst information processing certainly contributes to the self-controlled benefit, this is likely driven through motivational process (Graham & Golan, 1991; Grand et al., 2017; Ikudome et al., 2019; Kok, Komen, van Capelleveen, & van der Kamp, 2020; Legault & Inzlitch, 2013; Lemos et al., 2017; Lewthwaite et al., 2017; Mckay & Ste-Marie, 2020; Patall et al., 2013; Wulf & Lewthwaite, 2016).

With regards to children's limited attentional capacity (Brocken et al., 2016), it is important to consider how the timing and content of verbal feedback can impact children's motor learning (see Ste-Marie et al., 2012 for review). For example, where observational feedback models are used, verbal cueing should be presented after a demonstration and should focus attention towards movement outcomes (Ste-Marie, Clark, & Latimer, 2002). Additionally, younger children (e.g., aged 8yrs) rely on visual coding but require verbal instruction to interpret visual cues for enhanced goal-action coupling of the motor system (Renshaw et al., 2019), however if presented concurrently then it may negatively impact motor learning. In contrast, older children (e.g., aged 11yrs) use their advanced cognitive skills to couple verbal and visual cues to develop more effective movement strategies. However, verbal instruction (e.g., open like a flower) may only be effective when it is metaphorical as younger children may not understand complex movement terminology, whilst older children use metaphors to interpret cues based on past individual movement experiences (Chatzopoulos et al., 2020; Sawada, Mori, & Ishii, 2002). Clearly there is a need to optimise feedback when it is requested based on developmental characteristics. The review by Ste-Marie et al. (2012) indicates that an EF could be crucial in feedback approaches given children's use and reliance on visual coding. Future research should explore the effectiveness of combing AS and EF given their potential interactions.

3.2.2.1 Summary: Autonomy support

This review highlights that supporting children's autonomy through the provision of choice can be effective to enhance motor performance and learning. Although various approaches to the provision of choice have been demonstrated, other methods for AS application have yet to be explored (e.g. AS language). At present, the mediators associated with AS (e.g., self-efficacy and positive affect) and performance may be dependent on the approach of AS (e.g., choice of when to view self-observation; Ste-Marie et al., 2016). Whilst some research shows that information processing mediates the self-controlled benefits the role of motivation in error processing and focusing attention should not be ignored (e.g., Grand et al., 2017). Moreover, developmental characteristics (e.g., age, cognitive capacity) and task demand may moderate the AS benefit, particularly when children are provided the opportunity to self-regulate feedback. Overall, AS is a key factor in optimising children's motor learning, but more research is required to understand how opportunities for AS impact children's motor leaning and motivation (Palmer, Chinn, & Robinson, 2017; Pattal et al., 2008; Tompsett, Sanders, Taylor, & Cobley, 2017), and how AS interventions can be applied into ecologically valid settings (Raabe et al., 2019). Physical education teachers and sports coaches should allow children to exercise control over the practice environment to enhance their motor learning potential.

3.3 Other lines of research with OPTIMAL variables

The benefits of OPTIMAL approaches extend into children with various developmental issues although current understanding is limited. For example, reducing perceptions of error can augment movement form and heighten movement engagement for children with intellectual disabilities (Capio, Poolton, Sit, Eguia, & Masters, 2013). Additionally, self-selected feedback (AS) improved dart throwing accuracy in children (9-11 yrs) with developmental coordination disorder through enhanced information processing (Ste-Marie et al., 2013; Zamani, Fatemi, & Soroushmoghadam, 2015), however the Zamani et al. (2015) did not consider or measure the motivational impacts of AS. Furthermore, Van Cappellen et al. (2018) found that an EF enhanced motor learning in children with developmental coordination disorder by freeing up visuospatial working memory (a key factor in goal action coupling) supporting previous work that interventions for developmental coordination disorder should aim to reduce working memory load (Alloway, 2007). Similarly, an EF freed up attentional capacity and improved motor learning in children with intellectual difficulties (low IQ's) and attention-deficit hyperactivity disorder (Chiviacowsky et al., 2013; Saemi et al., 2013). However, in children with visual impairment the benefits of an EF may be moderated by impairment severity (McNamara et al., 2017). Yet, visual information did not mediate EF benefits in adults and adolescents with severe visual impairment in discrete, locomotion and maximal velocity tasks respectively (Abdollahipour et al., 2019; McNamara, et al., 2019[2]). These findings further suggest that age, motor experience, task type and focus preference/familiarity may have a more profound influence on children's motor learning in comparison to the role of acquiring key visual information (Fathi Khatab et al., 2018; McNamara et al., 2017; McNamara et al., 2019; Maurer & Munzert, 2013; Wulf et al., 2001). Additionally, task difficulty may moderate effort perceptions and the benefits of an EF in children with cerebral palsy, but an EF is generally effective under constant practice conditions (Pourazar et al., 2017). Although further research is required, these findings show that OPTIMAL approaches can enhance motor learning in children with different developmental needs.

In another line of research, combining OPTIMAL variables has demonstrated to have additive benefits on children's motor learning and motivation despite being heavily underexplored. Wulf, Chiviacowsky and Cardozo (2014) found that combining AS (incidental choices) and EE (false-social comparative feedback) augmented motor learning through increased self-efficacy and motor competence supporting predictions of the

[2] McNamara et al., (2019) excluded as the mean age (16.54yrs) exceeded that set out in the inclusion criteria.

OPTIMAL theory (Wulf & Lewthwaite, 2016). Additionally, Abdollahipour, Nieto, Psotta and Wulf (2017) demonstrated that EF (focus on the path of the ball) and choice of ball colour (AS) independently contributed to bowling performance, but, when combined, children's motor learning doubled. However, EF instructions may not have been specific enough for 8-year-old children as there was no clear instruction of when to focus attention and no intended movement effect/outcome was promoted (Petranek et al., 2019). This is further evidenced by a manipulation check which revealed that 70% of children reported a focus on the pins (i.e., the target) which was not highlighted by EF instruction. However, this finding further advocates that children rely on visual coding to promote an EF and task relevant visual cues specified by verbal instructions (Marchant, Griffiths et al., 2018; Renshaw et al., 2019). Furthermore, it may be less-than-optimal to apply each variable at a different stage of skill process given children's limited information processing capacities. For example, choice was provided pre-motor planning whilst EF instruction and feedback were provided (presumably) at the motor planning stage and post-movement execution respectively. Lastly, the effects of combining all three OPTIMAL variables on children's motor learning is yet to be explored despite its advantageous effects in adults (Wulf, Lewthwaite et al., 2018). Future research should explore how all OPTIMAL factors can be integrated into children's motor learning settings.

4. Considerations of OPTIMAL approaches

This review has highlighted several approaches to optimise children's motor learning, yet, given that instructional language is a critical factor in all motor learning research (and physical education settings) (Rink, 2013), the impact of instructional language needs to be broadly considered across all OPTIMAL approaches. For example, some EF instructions appear to use autonomy controlling language (e.g., the stick *needs* to push the puck faster;

Agar et al., 2016) which may confound the EF advantage. Additionally, the benefits of AS in the form of self-selected feedback could be confounded if it does not appropriately promote an optimal EF distance (Ste-Marie et al., 2012; Wulf & Su, 2007). Nevertheless, the language used within EF instructions and feedback needs to be carefully considered as developmental differences in comprehension, cognition and motor repertories can critically impact its effectiveness on motor learning (Petranek et al., 2019). Moreover, the presence of visual aids (e.g., a cone to jump towards) to promote an EF may inadvertently enhance expectancies by increasing the perceived attainability of the movement goal (Marchant, Griffiths et al., 2018; Coker, 2016), whilst implicit manipulations (e.g., illusions to make target size appear larger) may inadvertently promote an EF (McKay et al., 2015; Simpson et al., 2020). Importantly, each OPTIMAL factor can influence another and potentially confound their benefits on motor learning. Yet, appropriately integrating OPTIMAL factors into a motor learning environment could optimise children’s FMS development given their developmental characteristics. For example, a physical education teacher may allow a student to self-select performance criteria (AS and EE) (Asadi, Farsi, Abdoli, Saemi, & Porter, 2019; Simpson et al., 2020) by using a cone (EF) in a standing long jump task (Marchant, Griffiths et al., 2018; Simpson et al., 2020). Concise EF instructions could then direct attention to the cone in an autonomy supportive manner (Hooyman et al., 2014). Future research should consider how the impact of one OPTIMAL factor may influence another OPTIMAL factor (e.g., EF instructions which are autonomy controlling) (Simpson et al., 2020).

4.1 Future research directions

The current evidence indicates that OPTIMAL factors generally have a positive impact on children’s motor learning. However, in comparison to adults there is relatively little research (Lewthwaite & Wulf, 2017). For example, enhancing expectancies and providing AS has not always improved motor learning in adults, suggesting potential problems with some methodological approaches. Future work should continue to examine how OPTIMAL variables impact children's motor learning. Additionally, in terms of the range of motor skills addressed, there is a skewness towards object manipulation skills and a further bias towards throwing skills. Furthermore, most studies examine each FMS in isolation and therefore do not accurately reflect the nature of movements in real-world settings (e.g., physical education lessons), therefore it is unclear whether OPTIMAL variables are effective across the full and combined FMS range. Assessing how physical education teachers currently apply OPTIMAL variables and the impact of teacher-training interventions could be critical to improve children's engagement and achievement in physical education (Cheon, Reeve, & Moon, 2012) and should be targeted in future research. Moreover, this review has raised several important developmental issues that need be addressed (e.g., comprehension) yet few studies have directly examined the relationship between developmental status and OPTIMAL theory application. Considering these limitations future studies should aim to:

1) Apply OPTIMAL variables across the full FMS range, with a focus on locomotion and stability skills.
2) Provide clear conceptual and theoretical methodologies when selecting child and adolescent populations given their developmental differences.
3) Examine OPTIMAL factor effects on FMS in more ecologically valid settings (e.g., physical education lessons) and use more dynamic tasks to incorporate all aspects of FMS to better reflect real-world movements.

5. Conclusion

This review has highlighted that an EF, EE and AS are key attentional and motivational factors in children’s motor performance and learning. The positive effects extend across the full range of FMS, but more research is required regarding the motivational factors of EE and AS. Additionally, children’s developmental characteristics can impact the effectiveness of EF, EE and AS approaches. The current findings have implications for movement professionals working within children’s motor learning settings (e.g., physical education teachers), and we have exampled a method in which an EF, EE and AS can be used to optimise children’s motor learning in a real-world setting. Overall, the OPTIMAL theory can be considered a key framework for children’s motor learning.

Declaration of interest

The Authors declare that there is no conflict of interest. This research did not revive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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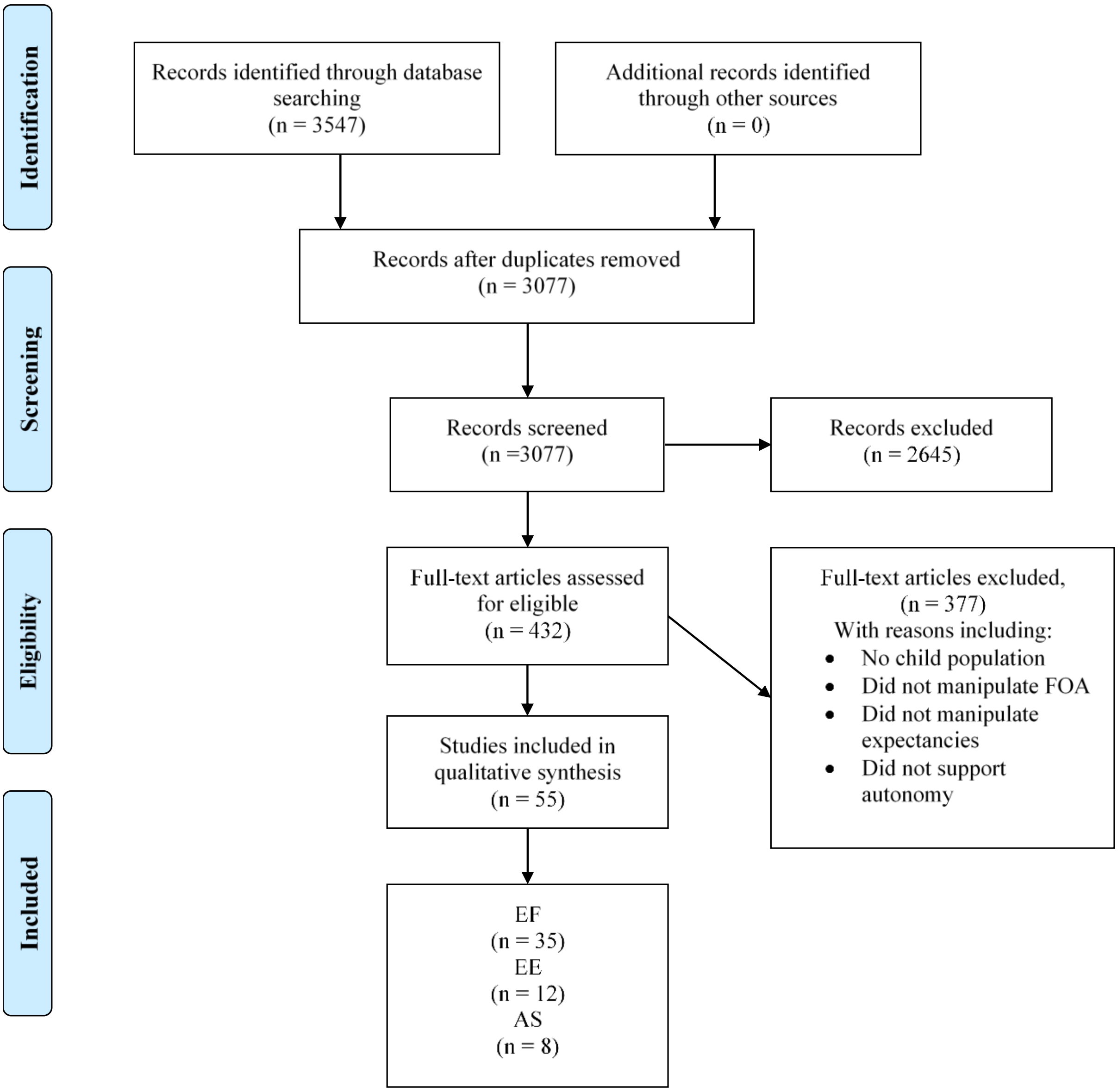

Figure 1. PRISMA flow chart for study selection within the systematic review.

Table 1. Overview of focus of attention research in child populations

Author	Task	FMS addressed	Participants	Measures	Result	Outcomes/conclusions	Manipulation check
Bodasinska et al. (2019)	Football juggling	OM	TDC N = 22m Mean age = 10.6 (0.5)	Number of touches	EF > IF and CT IF > CT	An EF increased movement effectiveness and performance. Yet, an IF may be beneficial in early motor learning by shorting the kinematic chain. Whilst an EF was most beneficial to performance, children may not rely on a single focus of attention.	Y
Li et al. (2019)	Suprapostural pole-holding task	ST	TDC N = 95 Mean age = 12.47 (0.03) DCD N = 91 Mean age = 12.45 (0.04)	Pole movements Postural sway	EF > IF and CT	An EF enhanced goal action coupling leading to significantly reduced postural sway and pole movements in TDC and children with DCD. This study supports predictions of the OPTIMAL theory (i.e., an EF enhanced goal-action coupling).	Y
Petranek et al. (2019)	Overhand throw	OM	TDC N = 65 Age range – 6-7	Psychomotor assessment Knowledge assessment	IF > EF	Children’s learning improved under higher feedback frequencies yet children’s developmental status (e.g., comprehension) appears to influence the attentional focus effect. The constrained action hypothesis may not apply to young children.	N
Schwab et al. (2019)	Soccer free kick technique	OM	TDC N = 20	Rotational ball velocity (RBV)	EF > IF	Movement form and performance increased under EF conditions, yet motivation and reinvestment increased in both groups suggesting that the connections between attention, motivation and performance is not	N

			Age groups – under 15s and under 17s Adults N = 36 Age not stated	Linear ball velocity (LBV) Questionnaire (Momentary feeling, task enjoyment, difficulty and motivation) Movement reinvestment		as simple as outlined in the OPTIMAL theory.	
Shin et al. (2019)	One-legged balance task	ST	TDC N = 24 (12m, 12f) Mean age = 10.90 (2.20)	Centre of pressure: range, distance, velocity	EF = IF and CT	Despite no significant differences, adjustments in balance where smaller in the EF compared to the IF condition. Children aged between 8-12-years go through a transition phase from an IF to an EF for effective motor learning.	N
Tse (2019)	Beanbag throwing	OM	High functioning autism N = 65 (44m, 21f) Mean age = 10.01 (0.04)	Mean radial error	IF > EF and CT	An IF group had greater throwing accuracy in retention but there were no differences in practice. An IF may more effectively facilitate motor learning in children with autism spectrum disorder due to their reliance of proprioception.	Y
Coker (2018)	Standing long jump	LO	TDC N = 26 (7m, 19f) Mean age = 12.58 (0.56)	Jump distance (cm) Take off projection angles	EF > IF EF = CT	An EF enhanced jump distance and decreased projection-take-off angles supporting predictions of the constrained action hypothesis. Cuing attention to the arms did not constrain the motor system in young adolescents.	N
Fathi Khatab et al. (2018)	Dart throwing	OM	TDC, DCD, adults	Accuracy (points)	Mixed results	Adults performed better using an EF. TDC children performed better under IF	N

			N = 60 (20 in each population) Children's age range = 7-11 Adults age range = 19-23			conditions. No differences were found in children with DCD. This study highlights the potential effect of different developmental characteristics on the attentional focus effect.	
Krajenbrink et al. (2018)	Slingerball throwing	OM	TDC N = 169 (86m, 76f) Mean age = 10.64 (1.19) Mean age range = 8.26-12.80	MABC2 Test Automated working memory assessment (AWMA) Throwing Accuracy (points)	EF > IF	An EF led to higher throwing accuracy in practice but not in retention. Working memory capacity did not predict motor learning. Movement automation did not differ under EF or IF conditions.	Y
Marchant, Griffiths et al. (2018) (experiment 1)	Standing long jump	LO	TDC N = 44 (23m, 21f) Mean age = 7.35 (1.7)	Jump distance (cm)	EF > IF and CT	Young children jumped further when an EF instruction directed attention towards a target cone as compared to IF and CT conditions. No differences between control and IF.	N
Marchant, Griffiths et al. (2018) (experiment 2)	Standing long jump	LO	TDC N = 54 (24m, 30f) Mean age = 8.41 (0.5)	Jump distance (cm)	EF-far > EF-near, IF and CT	The presence of a cone in EF-far condition may have activated greater hierarchical mechanisms to enhance goal-action coupling. This study highlights that attention and motivation are not necessarily separate characteristics.	N

Van Abswoude et al. (2018)	Golf Putting	OM	TDC N = 25 (13m, 12f) Mean age = 10.4 (1.1) Age range = 8-12	Radial error Automated working memory assessment (AWMA) Movement specific reinvestment scale (MSRS) Focus preference	EF = IF	Performance improved regardless of attentional focus. Task-specific focus preference was moderately related to differences in performance. Developmental differences are a key factor in children's motor performance.	Y
Van Cappellen et al. (2018)	Slingerball throwing	OM	DCD N = 26 (23m, 3f) Mean age = 6.92 (1.70) Age range = 4-12	MABC2 test Automated working memory assessment (AWMA) Throwing Accuracy (points)	EF = IF	An EF feedback enhanced visuospatial working memory capacity yet throwing accuracy improved regardless of attentional focus. The mechanisms and task constraints that influence learning with attentional focus are not yet understood.	N
Abdollahipour & Psotta (2017)	Catching task	OM	TDC N = 24 (5m, 15f) Mean age = 8.8 (0.8)	Number of catches	EF > IF, CT	An EF is effective to coordinate the motor systems degrees of freedom and to produce optimal motor responses. Where vision is critical in motor tasks, an IF may reduce effective goal-action coupling.	Y
Ashraf et al. (2017)	Vertical jump	LO	TDC N = 20	Vertical jump height	EF > IF, CT	Electromyography (EMG) activity was significantly reduced in the EF condition resulting in greater jump distance. These	N

			Mean age = 9 (0.94)	EMG Root Mean Square Error (RMSE)		results predictions of the constrained action hypothesis.	
McNamara et al. (2017)	Balance platform task	ST	Visual impairment N = 18 (9m, 9f) Mean age = 11.64 (2.25)	Root Mean Square Error (RMSE)	Mixed results	Children with moderate visual impairment improved under EF conditions whilst children with profound visual impairment did not differ between conditions. The benefits of an EF may depend on the severity of visual impairment.	Y
Pourazar et al. (2017)	Beanbag throwing	OM	Cerebral palsy N = 30m Mean age = 10.98 (1.27)	Accuracy (points)	EF > IF, CT	EF benefits extend into child populations with cerebral palsy. A lack of differences in the transfer test suggests that task difficulty may moderate effort perceptions in children with cerebral palsy.	N
Palmer et al. (2017)	Test of Gross Motor Development-2nd Edition	OM	TDC N = 44 (20m, 24f) Mean age = 7.7	Test of Gross Motor Development-2nd Edition scoring system	EF > IF, CT	An EF was generally more effective to FMS performance but variations in wording between conditions can have a significant impact on the execution of FMS	N
Roshandel et al. (2017)	Dart throwing	OM	TDC, Adults N = 30 (in each group) Adults mean age = 32 (6.65) Children Mean age = 10.32	Radial error	Mixed results	Children performed similar under EF and IF instructions whilst adults performed better with an EF as compared to an IF. Developmental cognitive differences may explain the findings.	N

Teixeira da Silva et al. (2017)	Ballet pirouette	ST	TDC N = 38f Mean age = 9.5 (0.8)	Motivation ratings Pirouette scores (degrees turned) Thoughts during practice (open ended questions)	EF > IF	An EF lead to increased perceived competence, greater satisfaction, greater importance of performing well and performance. This study highlights that an EF can have motivational as well as attentional benefits.	Y
Tse & van Ginneken (2017)	Dart throwing	OM	TDC N = 102 (66m and 36f) Mean age = 10 (4.1)	Mean radial error Movement specific reinvestment scale (MSRS)	Mixed results	Children with high conscious control propensities performed better under an IF whilst children with low conscious control propensities performed better under an EF. Developmental differences may underpin the attentional focus effect on motor performance.	Y
Agar et al. (2016)	Shuffleboard task	OM	TDC N = 48 Age range- 5 - 8 and 9 - 12	Accuracy (points)	EF = IF	No significant differences were found between attentional foci. Older children performed better than younger children. Skill-based instructions may benefit practice regardless of FOA direction.	N
Brocken et al. (2016)	Golf putting	OM	TDC N = 60 (26m, 34f) Younger group- Mean age = 8.94, (0.45)	Automated working memory assessment (AWMA) Radial error	EF > IF	EF demonstrated greater improvements in putting accuracy compared to IF in both age groups. Verbal working memory capacity was found not to be a predictive factor in motor learning.	N

			Age range = 8-9 Older group- Mean age = 11.66 (0.43) Age range = 11-12				
Flores et al. (2016)	Pedalo dynamic balance task	ST	TDC N = 74 (36m, 38f)	Movement completion time	Distal EF > CT	Only a distal EF improved performance in the transfer test. Boys displayed greater learning than girls under both EF conditions highlighting that gender may moderate the EF advantage.	N
Perreault & French (2016)	Basketball free throw	OM	TDC N = 42 (28m, 28f) Age range = 9-11	Free throw performance Thoughts during learning (verbal reports)	EF = IF, CT	No significant differences between groups for performance. Retrospective feedback statements suggest an EF may have contributed to superior performance in retention for moderate and high performers.	Y
Abdollahipour et al. (2015)	180-degree gymnast turn	LO	TDC N = 24 (2m, 22f) Mean age = 12 (2.1)	Jump height. Movement form (scored by judges)	EF > IF, CT	EF produced superior movement form and jump heights. IF produced greater movement form than CT. The authors conclude that form-based skills can be enhanced easily by appropriate EF instructions.	N
Flores et al. (2015)	Pedalo dynamic balance task	ST	TDC N = 108 Age range = 6 and 10	Movement completion time	EF > IF, CT EF-distal > EF-proximal	An EF further from the body can maximise performance. Both EF-distal and proximal resulted in faster completion times regardless of age.	N

Perreault & French (2015)	Basketball free throw	OM	TDC N = 28 (14m, 14f) Age range = 9-11	Free throw performance Thoughts during learning (verbal reports)	EF > IF	EF feedback produced a significant learning advantage. The study provides support for the self-invoking trigger and the constrained action hypothesis, that is, a focus on the self is detrimental to performance.	Y
Chow et al. (2014)	Standing long jump	LO	TDC N = 36m Mean age = 9.93 (0.33)	Jump distance, kinetics and kinematics	EF > IF	EF was generally more effective to learning. Larger joint range of motion and a larger horizontal impulse led to increased jump distance. The inclusion of constraints to encourage self-adjustment had a beneficial effect. Overall, an optimal EF may be task and individual specific.	Y
Hadler et al. (2014)	Forehand tennis strokes	OM	TDC N = 45 (24m, 21f) Mean age = 10.98 (0.72) Age range = 10-12	Shot accuracy (points)	EF > IF, CT	Short cued EF instructions can positively impact children's motor learning.	N
Becker and Smith (2013)	Pedalo dynamic balance task	ST	TDC N = 48 (24m, 24f) Age range - 8-10 Adults. N = 48 (24m, 24f)	Movement completion time	Mixed	Focus of attention did not influence performance in the simpler task but an EF resulted in faster times in male participants only. This study indicates that task complexity and sex moderate the attentional focus effect.	Y

			Age Range – 19-26				
Chivacowsky et al. (2013)	Beanbag throwing	OM	Intellectual disabilities N = 24 (10m, 14f) Mean age = 12.21 (1.31)	Throwing accuracy (points)	EF > IF	An EF allowed attentional capacity to be freed up to re-parametrise movements in the transfer test where performance was improved. This suggests that an EF is generalisable across skill sets.	Instruction comprehension only.
Maurer & Munzert (2013)	Basketball free throw	OM	Expert N = 23f Mean age = 16.3 (1.29)	Free throw performance (points)	IF = EF	No significant differences in performances where found. However, skill-IF produced slightly better performances than an environmental-EF. Focus familiarity may have influenced motor performance.	Y
Saemi et al. (2013)	Ball throwing	OM	ADHD N = 20 Mean age = 10.1 (0.85)	Throwing accuracy (points)	EF > IF	This is the first study to show that an EF can develop motor skills in children with ADHD.	N
Wulf et al. (2010)	Soccer throw-in	OM	TDC N = 48 (18m, 30f). Age range = 10 - 12	Throwing distance (m) Movement form Throwing accuracy	EF > IF	EF feedback presented after every trial was beneficial to movement form relative to EF feedback after every third trial, and IF feedback. This study highlights potential motivational effects of EF feedback.	N

Emanuel et al. (2008)	Dart throwing	OM	TDC and Adults N = 66 Children = (20f, 14m) Adults = (16m, 16f) Mean age (children) = 9.04 (0.35) Mean age (adults) = 28.73 (4.23)	Mean radial error Bivariate radial error	IF > EF	Adults benefited from an EF whilst children performed better under IF conditions indicating that children may benefit from an IF in early motor learning.	N

Notes: Where three or more authors are reported only the leading author is cited. FMS = foundational movement skills. OM = object manipulation skills. LO = locomotion skills. ST = stability skills. N = number of participants. m = male. f = female. Age (SD) reported in years. TDC = typically developing children, DCD = developmental coordination disorder, ADHD = attention deficit hyperactivity disorder. EF = external focus of attention. IF = internal focus of attention. CT = control condition or group. > = outperformed. Y = yes, N = no.

Table 2. Overview of enhanced expectancies research in child populations

Author	Task	FMS addressed	Participants	Measures	Expectancy manipulation	Outcomes
Bahmani et al. (2018)	Golf putting	OM	TDC N = 30m Mean age = 10.66 (0.41)	Radial error Self-efficacy Perceptions of hole size	Perception of target (hole) size manipulated through visual illusion.	A perceived large target produced more accurate putts and higher self-efficacy. Enhancing perceptions of success through implicit manipulations can improve children's motor learning.
Goncalves et al. (2018)	Basketball free throw	OM	TDC N = 26 Mean age = 9.65 (0.91) Age range = 9-12	Subject experience Accuracy (points)	Positive (false) social comparative feedback. Performance 20% better than similar peers.	Positive feedback led to greater accuracy and higher levels of perceived competence, importance of doing well and persistence with the task. This study highlights the motivational role of feedback on children's motor learning.
Chiviacowsky & Drews (2014) (Experiment 1)	Soccer kicks	OM	TDC N = 40 (10f, 30m) Mean age = 10 (0.32)	Accuracy (points)	Conceptions of ability. Practice (non-generic feedback) vs talent (generic feedback).	Conceptions of ability can be altered with feedback. Positive practice beliefs (non-generic feedback) produced better performances in self-threating environments. Generic feedback, which frames talent as a fixed state, can degrade intrinsic motivation.
Chiviacowsky & Drews (2014) (Experiment 2)	Beanbag throwing	OM	TDC N = 41 (30m, 10f) Mean age = 10.5 (0.51)	Accuracy (points)	Conceptions of ability. Generic feedback (inherent ability) vs non-generic feedback (practice).	Conceptions of inherent ability can have permanent effects on children's motor learning and motivation. Non-generic feedback which framed the skill as learnable led to greater error recovery.
Capio, Poolton et al. (2013)	Beanbag throwing	OM	TDC	Absolute error	Perceptions of error-	Reducing perceptions of error improved accuracy, movement form and dual task performance. Error reduced

			N = 216 Mean age = 9.16 (0.96)	Movement form	Reduced error perceptions by increasing target size throughout practice. Increased error perceptions by reducing target size throughout practice.	learning improved girls' movement form and children with low motor ability. Errorless learning can facilitate greater experiences of success via EE.
Capio, Poolton, Sit et al. (2013)	Beanbag throwing	OM	Intellectual disabilities N = 39 Age Range= 4-11	Absolute error Movement form	Reduced error perceptions by increasing target size throughout practice. Increased error perceptions by reducing target size throughout practice.	Errorless learning augmented movement form, throwing activity during free play and dual task performance. Perceptions of success can heighten movement engagement for children with intellectual disabilities.
Drews et al. (2013)	Beanbag throwing	OM	TDC N = 120 (66m, 54f) Age range= 6-14	Accuracy (points)	Conceptions of ability. Inherent ability vs acquirable skill	Older participants demonstrated higher accuracy scores than younger participants. Instructions that emphasise that a skill can be learnt through practice improved throwing accuracy. The study suggests that 14-year-old children are vulnerable to the threat of their inherent ability is being exposed.
Avila et al. (2012)	Beanbag throwing	OM	TDC N = 32 Mean age = 10.4 (0.36)	Accuracy (points) Perceived competence	Positive (false) social comparative feedback about performance in comparison to other schools in the city.	Positive (false) social comparative feedback enhanced throwing accuracy and perceived competence, highlighting the motivational importance of feedback on children's motor learning.
Saemi et al. (2011)	Beanbag throwing	OM	TDC N = 28 Mean age = 10.61 (0.88)	Accuracy (points) Perceived competence Enjoyment Effort	Veridical feedback provided after good and poor trials.	Learning and intrinsic motivation were enhanced by providing knowledge of results after good trials. The findings provide evidence of the motivational role of positive feedback.

Ste-Marie et al. (2011)	Trampoline routines	LO	TDC N = 31 (13m, 18f) Age range – 7-13 (mean age = 10.2)	Physical performance Goal setting Strategic planning Intrinsic motivation Self-efficacy	Positive (video) self-modelling.	Children acquired a trampoline routine better when provided with positive video feedback of their performance as compared with verbal instructions alone. The performance advantages cannot be explained through intrinsic motivation or self-efficacy highlighting that cognition may moderate the positive feedback effect.
Zetou et al. (2008)	Volleyball “setting” and “passing”	OM	TDC N = 32f. Mean age = 12.8 (0.53)	Setting Passing Self-efficacy	Video self-modelling.	Self-observation when paired with verbal cuing improved performance versus cuing alone. Self-efficacy was also increased in the self-observation group. The study suggests that positive feedback should be provided in self-observation models to enhance intrinsic motivation.
Clark & Ste-Marie (2007)	Swimming	LO	TDC N = 33 (13m, 20f) Mean age = 8.3 (1.2)	Physical performance Intrinsic motivation Self-satisfaction	Positive (video) self-modelling.	Positive self-modelling improved swimming performance in comparison to a self-observation and control group. Self-efficacy, intrinsic motivation, self-satisfaction also increased because of positive self-modelling. This highlights that positive self-modelling is beneficial to children’s motor learning.
Law & Ste-Marie (2005)	Figure skating	LO	TDC N = 19f Mean age = 13.8 (1.87)	Jump performance Self-efficacy State anxiety Situational motivation	Positive (video) self-modelling.	Jumping performance did not differ between physical practice (only) and self-modelling conditions but both conditions were perceived as positive. This study highlights that self-perceptions of performance and individual characteristics may moderate the benefits of self-modelling interventions.

Notes: Where three or more authors are reported only the leading author is cited. FMS = foundational movement skills. OM = object manipulation. LO = locomotion. ST = stability. N = number of participants. m = male. f = female. Age (SD) reported in years. TDC = typically developing children. EE = enhanced expectancies. All manipulations were successful except Law and Ste Marie (2005).

Table 3. Overview of autonomy support research in child populations

Author	Task	FMS addressed	Participants	Measures	Autonomy support	Outcomes
Goudini et al. (2019)	Taekwondo (ap chagi)	LO	TDC N = 30m Mean age = 12.43 (2.08)	ap chagi technique Intrinsic motivation	Could request knowledge of performance feedback on 5 out of 10 trials.	Self-controlled feedback (AS) improved motor performance in comparison to a control and yoked group. Additionally, intrinsic motivation was enhanced (especially perceived competence). The authors suggest that positive feedback could further enhance learning and motivation.
Lemos et al. (2017)	Ballet	ST	TDC N = 24f Mean age = 10.58 (0.5)	Movement form Self-efficacy Positive affect Thoughts during practice	Could request video demonstrations of all five ballet positions prior to any trial.	AS improved movement form and led to more positive thoughts during practice. A control group reported negative self-focused thoughts. This study highlights motivational underpinnings of choice and motor learning.

Ste-Marie et al. (2016)	Trampolining	LO	TDC N = 100 (46m, 54f) Mean age = 11.1 (1.87)	Self-efficacy Intrinsic motivation Trampolining performance	Could request feedback in the form of (video) self-observation. Verbal instruction directed attention whilst viewing the video and a prescriptive statement about how to correctly perform the next trial was provided.	AS resulted in significantly more skill progressions than their yoked counterparts. Path analysis revealed that self-efficacy and intrinsic motivation did not moderate performance when autonomy is supported through self-controlled provisions.
Zamani et al. (2015)	Dart throwing	OM	DCD N = 24 Age range = 9-11	Accuracy (points)	Feedback could be requested on 50% or 75% of trials.	AS produced better performance in retention. Self-controlled feedback, when received at a higher frequency, led to better learning for children with DCD.

Ste-Marie et al. (2013)	Trampolining	LO	TDC N = 60 (30m, 30f) Mean age = 11.2 (1.89) Age rang = 7-15	Self-efficacy Intrinsic motivation Trampolining performance Perceived success Perceived choice	Could request feedback in the form of (video) self-observation. Verbal instruction directed attention whilst viewing the video and a prescriptive statement about how to correctly perform the next trial was provided.	Learner-controlled feedback group displayed greater self-efficacy, performance, intrinsic motivation scores and perceived choice measures. Regression analysis revealed that choice and self-efficacy were significant predictors of physical performance in retention.

Bokums et al. (2012)	Overhead volleyball serves	OM	TDC N = 48f Mean age = 13.33 (0.72) Age range = 12-14	Accuracy (points) Preference of when to receive feedback Frequency of feedback	Controlled the frequency of feedback.	No interaction between frequency of feedback and performance. Highly anxious girls requested feedback more often than low anxious girls. Feedback was requested more often after accurate trials compared with less accurate trials. This study highlights the impact of children's developmental characteristics on AS.
Chiviacowsky, de Medeiros et al. (2008)	Beanbag throwing	OM	TDC N = 26 Mean age = 10.5 (0.5)	Accuracy (points) Frequency of feedback	Could receive feedback upon request.	AS benefited performance in comparison to yoked feedback. Providing learners, the opportunity to receive knowledge of performance has advantageous effects on older children's motor learning.
Chiviacowsky, Wulf et al., (2008)	Beanbag throwing	OM	TDC	Accuracy (points) Frequency of feedback	Could receive feedback upon request.	Participants who requested feedback more often performed better than those who requested less feedback. This study suggests that children may request feedback, if awarded the option, at a lower than optimal rate.

N = 60 (32m, 28f) Mean age = 10.5 (0.8)

Notes: Where three or more authors are reported only the leading author is cited. FMS = foundational movement skills. OM = object manipulation. LO = locomotion. ST = stability. N = number of participants. m = male. f = female. Age (SD) reported in years. TDC = typically developing children. DCD = developmental coordination disorder. AS = autonomy support. All manipulations were successful expect Bokums et al., (2012).

Table 4. Overview of focus of attention instructions used in research with child populations.

Author	Task	External focus instructions	Internal focus instructions	Control
Bodasinska et al. (2019)	Football juggling	"*When you are juggling, focus on the ball*"	"*When you are juggling, focus on your foot*"	"*Perform the task to the best of your abilities*"
Li et al. (2019)	Suprapostural pole-holding task	Focus attention on the midpoint of the pole only	Pay full attention on their hands	N/A
Petranek et al. (2019)	Overhand throw	Feedback statements - 1. Make a "T", ball away from target (ball to back wall) 2. Bring ball past your ear 3. Step with your sneaker closest to the wall 4. Follow through and send the ball to the target	Feedback statements - 1. Arms out wide, side to target 2. Bring your throwing hand past your ear 3. Step with your opposite foot, closest to the wall 4. Follow through and point your finger to the target	N/A
Schwab et al. (2019)	Soccer free kick technique	1. Make sure to hit the ball just below its mid-line to lift the ball 2. Make sure to hit the ball only very briefly 3. Try to increase the speed to … km/h 4. Try to reduce the ball spin to …. turns 5. Focus on your primary goal, to score a goal	1. Concentrate on hitting the ball exactly with the inner side of your foot 2. Stabilize your ankle and extend your toes when you hit the ball 3. Try to stop your kick leg after contact with the ball 4. During the shot your body should be positioned vertically above the ball 5. Jump off with your support leg as soon as you hit the ball and land sideways of your shot foot	N/A

Shin et al. (2019)	One-legged balance task	Stand on one leg by focusing on the markers placed in front	Stand on one leg while focusing on his/her lower limb movements	N/A
Tse (2019)	Beanbag throwing	1. Look at the target attentively for a few seconds 2. While throwing the beanbag, concentrate on its flight directly toward the target	1. Before throwing, concentrate on your arm position. Also, pay attention to your elbow movement 2. Bring your hand backward until the beanbag touches your ear. At the end of the throw, your elbow is fully straightened	N/A
Coker et al. (2018)	Standing long jump.	Focus on jumping as close as possible to the cone (3 metres away)	Legs - Focus on extending the knees as rapidly as possible Arms - focus on swinging the arms forward as rapidly as possible	N/A
Fathi Khatab et al. (2018)	Dart throwing	1. Focus on the target 2. When ready, throw the dart towards the dartboard 3. Follow the flight of the dart, focusing on it to strike the dartboard 4. Maintain your focus until the dart strikes the dartboard	1. Feel the weight of the dart 2. Flex your arm and bring the dart back 3. Be ready and feel the movement of your arm when you extend your arm forward 4. Feel the dart when it leaves your fingers 5. Think about throwing the dart differently to get it closer to the target	N/A
Krajenbrink et al. (2018)	Slingerball throwing	Swinging - Ensure the ball has a backspin while swinging Throwing - Ensure you let the ball go when it is directed towards the target Reminder - Pay attention to the ball	Swinging - Ensure your arm turns backwards whilst swinging Throwing - Ensure you let loose when your arm is right in front of you Reminder - Pay attention to your arm	N/A

Marchant et al. (2018) (experiment 1)	Standing long jump	"*Focus on jumping as close to the cone as possible*"	"*Focus on springing your legs as fast as possible when you jump*"	"*Jump*"
Marchant et al. (2018) (experiment 2)	Standing long jump	External-near: "*Jump as far past the start line as possible*" External-far: "*Jump as close to the cone as possible*"	"*Focus on extending your legs as rapidly as possible*"	"*Jump to the best of your ability*"
Van Abswoude et al. (2018)	Golf Putting	Move the club like a pendulum	Focus on moving their arms like a pendulum	N/A
Van Cappellen et al. (2018)	Slingerball throwing	Make sure the ribbon is slacker/tighter when you swing it Make sure the ball is lower/higher when you let it go Make sure the ball turns slower/faster before you let it go Make sure the ball is lower/higher when you let it go Make sure you let it go sooner/later	Make sure your arm is stretched less/more when you swing the ball Make sure your arm is lower/higher when you release it Make sure your arm turns slower/faster before you let go Make sure your arm is lower/higher when you release it Make sure you let go sooner/later	N/A
Abdollahipour & Psotta (2017)	Catching task	"*Concentrate on the ball*"	"*Concentrate on your hands*"	N/A
Ashraf et al. (2017)	Vertical jump	Concentrate on the rungs	Concentrate on the tips of their fingers	N/A
McNamara et al. (2017)	Balance platform task	"*On this trial we want you to focus on keeping the markers on the platform level*"	"*On this trial we want you to focus on keeping your feet level*"	N/A
Pourazar et al. (2017)	Beanbag throwing	Direct their attention to the target, beanbag, and beanbag course. While throwing the beanbag, participants in the external focus group were asked to	Focus on how their shoulder, arm, and fingers feel before and during the throw	N/A

		concentrate on its flight directly towards the target, focus on the beanbag (how it feels, its weight, and its position), and to look at the target after every 10 trials.		
Palmer et al. (2017)	Test of Gross Motor Development- 2nd Edition	**Striking a stationary ball -** Focus on hitting the centre of the ball with the bat **Stationary Dribble -** Focus on dribbling the ball five times on one side, hitting the same spot on the floor each time **Catch -** Focus on keeping your eye on the ball and reaching to catch the ball as it arrives **Kick -** Focus on making the ball hit the target directly in front of you **Overhand throw -** Focus on making the ball hit the target directly in front of you **Underhand roll -** Focus on pulling the ball behind you and step forward to roll the ball low to the ground	**Striking a stationary ball -** Focus on moving your arms as quickly as possible when hitting the ball and twisting your body **Stationary Dribble -** Focus on dribbling the ball five times with one hand **Catch -** Focus on lengthening your arms and then bring your hands together to grasp the ball **Kick -** Focus on swinging your leg as hard as you can **Overhand throw -** As you throw, focus on twisting your body and moving your arm as fast as you can **Underhand roll -** Focus on bending your knees as you bend your arm and push through your fingers	**Striking a stationary ball -** Grab the bat and strike the ball off the tee to one side of the room **Stationary dribble -** Dribble the ball five times and then catch **Catch -** catch the ball with two hands then drop the ball in the floor besides you **Kick -** run and kick the ball **Overhand throw -** throw the ball as hard as you can towards the wall **Underhand roll -** roll the ball towards the wall
Roshandel et al. (2017)	Dart throwing	1. Focus on the centre of the dart board	1. Feel the weight of the dart in their hand	N/A

		2. Slowly begin to expand upon the perspective of the dart board 3. Throw the dart to the target	2. Think about bending the elbow 3. Feel the dart while left fingertips	
Teixeira da Silva et al. (2017)	Ballet pirouette	Focus on a spotting point on the wall in front of them and fix their gaze on it for as long as possible	Focus on the initial position of their head relative to the wall in front of them and keep it in that position for as long as possible	N/A
Tse & van Ginneken (2017)	Dart throwing	Focus on the darts flight path	Focus on the movement of their throwing arm	N/A
Agar et al. (2016)	Shuffleboard task	Feedback - Attention was directed to the stick used to propel the puck in the desired direction or with appropriate force. Typical feedback examples included "*The stick needs to push the puck faster*" or "*The stick needs to push the puck slower*"	Feedback - Instructions were focused on body position, movements of the shoulder, stepping of the foot, pushing of the arm, and position of fingers (grip). Typical feedback examples included "*Step harder*," "*Swing your arm faster*," or "*Step and push your arm toward the centre*" [if shot was wide]"	N/A
Brocken et al. (2016)	Golf putting	"*Move the golf club like a pendulum*"	"*Move the arms like a pendulum*"	N/A
Perreault & French (2016)	Basketball free throw	Focus on balancing the ball on their hand like a waiter balances a tray Focus on creating backspin on the ball during release	Focus on making an L-shape with their arm and resting the ball on their finger pads Focus on snapping their wrist forward when releasing the ball	N/A
Flores et al. (2016)	Pedalo dynamic balance task	Proximal EF - Focus on pushing the platforms forward Distal EF - Focus on a marker positioned after the finish line	N/A	N/A
Abdollahipour et al. (2015)	180-degree gymnast turn	"*While airborne, focus on the direction in which the tape marker is pointing after the half turn*"	"*While airborne, focus on the direction in which your hands are pointing after the half turn*"	N/A
Flores et al. (2015)	Pedalo (balance task)	Proximal - Focus on pushing the platforms (under each foot) forward Distal - Focus on an orange maker positioned after the finish line	Participants focused on pushing their feet forwards	N/A
Perreault & French (2015)	Basketball free throw	Balance the ball on your hand like a waiter balances a tray	Make an L-shape with your arm and rest the ball on your finger pads	N/A

		Focus on a spot just above the rim Shoot the ball as if it is going over a volleyball net Try to make the ball spin backward when you release it	Line up your hand and eye with the basket Extend your knees and arms together as you shoot the ball Snap your wrist forward when releasing the ball	
Chow et al. (2014)	Standing long jump	1. Look at the target line on the mat as you jump 2. Try and reach out and point to the wall when you jump 3. Launch yourself into the air as you jump. Pay attention to the spot on the mat where you are landing	1. Pay attention to how your legs and feet push off the ground when you jump 2. Pay attention to how your arms swing forward in the air when you jump 3. Pay attention to the position of your feet on the mat when you are landing	1. Try your best when you jump 2. Do not forget to try your hardest 3 Lift your upper body and shoulders into the air as you jump Remember that this is a test of your strength. You should try to be the best in your class
Hadler et al. (2014)	Forehand tennis strokes	Movement of the racquet	Movement of the arm	N/A
Becker & Smith (2013)	Pedalo dynamic balance task	Focus on pushing the boards Forward	Focus on pushing their feet Forward	N/A
Chivacowsky et al. (2013)	Beanbag throwing	Participants told to focus their attention to the movement of the beanbag while throwing	Participants told to focus their attention on the movements of their throwing hand	N/A
Maurer & Munzert (2013)	Basketball free throw	Environmental external familiar and unfamiliar movement aspects- Participants chose four instructions from the list on where to focus attention:	Skill internal familiar and unfamiliar movement aspects- Participants chose four instructions from the list on where to focus attention:	N/A

		basket, front part of rim, middle of rim, ball falling through the basket, ball flight trajectory, high-test point of ball flight, rectangle of board, and back part of rim.	Straightening arm, snapping wrist, straightening legs, fluent leg arm coordination, elbow under ball, feeling ball's weight, weight on both feet.	
Saemi et al. (2013)	Ball throwing	"*Take the tennis ball with your dominant hand, and as accurately as possible throw it toward the target while concentrating on the ball, particularly the landing location of the ball*"	"*Take the tennis ball with your dominant hand, and as accurately as possible throw it towards the target while concentrating on the motion of your hand and wrist that is throwing the ball*"	Be as accurate as possible
Wulf et al. (2010)	Soccer throw-in	Feedback statements - 1. The sneakers should point at the target; keep them apart 2. Produce a "C" at the beginning of the throw 3. The grip should look like a "W" on the back of the ball 4. The ball should be behind you at the beginning of the throw 5. Propel the ball forward and release it in front of you, aiming at the target 6. There should not spin on the ball during flight 7. The ball should be released just in front of you 8. The sneakers should remain on the ground	Feedback statements - 1. The feet, hips, knees and shoulders should be aimed at the target, feet shoulder width apart 2. The back should be arched at the beginning of the throw 3. The grip should look like a "W" with the thumbs together on the back of the ball 4. The ball should start behind the head at the beginning of the throw 5. The arms should go over the head during the throw and finish by being aimed at the target 6. There should not spin on the ball during flight 7. The ball should be released just in front of the head 8. Feet should remain on the ground	N/A
Emanuel et al. (2008)	Dart throwing	Hold the dart with your right hand	On your right hand, place your thumb next to your middle finger and index finger Flex your elbow until your hand reaches your eye height	N/A

	Roll the dart and concentrate on its weight and position. Pay attention that the dart is parallel to the ground Bring the dart to eye level and feel the dart directly in front of you on your right Look at the target centre carefully for few seconds. Bring the dart toward your right ear and throw the dart While throwing the dart, concentrate on its flight directly toward the target After every 10 trials: Focus on the dart (how it feels, its weight and position) and look at the target	Before throwing, concentrate on your finger motion and the correct position Pay attention to your grasp and to the flexing and extending of your elbow Bring your hand backward, approximately to your ear, and while throwing extend all of your fingers together so that, at the end of the throw, your hand is directed forward, and your elbow is fully straightened After every 10 trials: Focus on how your arm and hand (elbow, wrist, and fingers) feel before and during the throw

Notes: Where three or more authors are reported only the leading author is cited. EF = external focus of attention; IF = internal focus of attention; CT = control condition or group. For details of the samples and effects of these conditions, see table 1.